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Annapolis Basin Soft-Shell Clam (Mya arenaria) Mortality Study: A Summary of Field and Laboratory Investigations

N.J. Prouse, T.W. Rowell, P. Wo[illegible], J.F. Uthe, R.F. Addison, D.H. Loring, R.T.T. Rantala, M.E. Zinck and D. Peer

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ANNAPOLIS BASIN SOFT-SHELL CLAM (*MYA ARENARIA*) MORTALITY STUDY: A SUMMARY OF FIELD AND LABORATORY INVESTIGATIONS.

by

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ABSTRACT

Prouse, N.J., T.W. Rowell, P. Woo, J.F. Uthe, R.F. Addison, D.H. Loring, R.T.T. Rantala, M.E. Zinck, and D. Peer. 1988. Annapolis Basin Soft-Shell Clam (*Mya arenaria*) Mortality Study: A Summary of Field and Laboratory Investigations. Can. Man. Rep. Fish. Aquat. Sci. No. 1987: vii + 19 pp.

In April 1987, soft-shell clams (*Mya arenaria*) in a small intertidal area of the Annapolis Basin, Nova Scotia, were found dead. Since live and apparently healthy clams were still found in the higher beach region at this location, it was decided to set up experimental plots in the area of dead clams to determine if mortality factors were still acting. A 100% mortality of transplanted experimental clams within two months indicated that this was the case. Although there is evidence from preliminary laboratory studies that predation by the ribbon worm, *Cerebratulus lacteus*, may have occurred, this is not believed to be the cause of the mortality. As part of an investigation to determine the cause of this mortality, sediment and clams were collected in October, 1987, from the dead clam area (DCA) and a nearby tidal flat as a control. In the laboratory, sediments, half of which were autoclaved to remove microorganisms, were placed into running seawater tanks into which healthy clams were transplanted. After three months no significant mortality of clams was observed in either the autoclaved or raw sediment from the DCA or the control areas. Body condition indices of all molluscs indicated that clams in the DCA sediment were not under greater stress than those in the control sediment. No significant amount of chlorinated pesticide residues or polychlorinated biphenyls were found in clam tissue from either collection site. The heavy metal concentrations in sediment from both areas were at natural background levels. *M. arenaria* survived in sediment collected from the DCA; possible reasons for the clam death and future plans are discussed.

RÉSUMÉ

Prouse, N.J., T.W. Rowell, P. Woo, J.F. Uthe, R.F. Addison, D.H. Loring, R.T.T. Rantala, M.E. Zinck, and D. Peer. 1988. Annapolis Basin Soft-Shell Clam (*Mya arenaria*) Mortality Study: A Summary of Field and Laboratory Investigations. Can. Man. Rep. Fish. Aquat. Sci. No. 1987: vii + 19 pp.

En avril 1987, on découvrait des myes (*Mya arenaria*) mortes dans un petit secteur intertidal du bassin d'Annapolis (Nouvelle-Écosse). Comme il y avait également des myes vivantes et apparemment saines dans le haut des plages de l'endroit, on décidait de transplanter des myes saines dans des parcelles expérimentales du secteur à myes mortes (SMM), afin de déterminer si les facteurs de mortalité étaient encore agissants. Il l'étaient, et le taux de mortalité des myes transplantées atteignit 100% en deux mois. Malgré des signes de prédation possible par le ver némertean *Cerebratulus lacteus*, on croit la

mortalité due à une autre cause. Dans le but d'en déterminer l'origine, on recueillit des sédiments et des myes dans le secteur affecté, ainsi qu'un échantillon-témoin dans une vasière proche. Au laboratoire, la moitié des sédiments fut autoclavée pour éliminer les micro-organismes. On plaça tous les sédiments dans des contenants d'eau de mer courante, dans lesquels les myes saines furent transplantées. Au bout de trois mois, on n'avait constaté aucune mortalité significative des myes dans les contenants, que les sédiments aient été autoclavés ou nature, prélevés dans le SMM ou dans l'échantillon-témoin. De plus, l'indice de condition de tous les mollusques visés révélait que les myes vivant dans les sédiments provenant du SMM n'étaient pas sous l'effet d'un plus grand stress que celles de l'échantillon-témoin. Enfin, on ne décelait aucune quantité notable de résidus de pesticide chloré ou de biphényle polychloré dans les myes du SMM, ni dans celles de l'échantillon-témoin, et les concentrations de métaux lourds dans les sédiments provenant des deux échantillons étaient comparables à celles du fond naturel. La *Mya arenaria* a donc survécu dans les sédiments prélevés dans le SMM. On se penche ici sur les causes possibles de la mortalité des myes et sur les mesures à envisager.

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INTRODUCTION

In response to fishermen's claims that catches of soft-shell clams (*Mya arenaria*) had been declining in the Annapolis Basin as a result of environmental changes, a generalized survey was conducted in April 1987 by the Biological Sciences Branch, DFO, over a number of clam flats (Rowell, Woo, and Peer, unpublished data). On one flat, that at Oak Point (Fig. 1), no live clams were found except in the uppermost reaches of the intertidal zone. An extensive area of flat was examined by digging with shovels and/or hacks (including sieving of bottom material with a 1.18 mm^2 mesh screen at a number of locations). Bottom substrate over the highest 20 m or so of beach was sand and sandy mud. Below this, the beach was very firm with only 1.5-2.0 cm of fine silt or mud over a darker, reduced, clay-like substrate. Throughout the area, the reduced layer was filled with empty clam shells: the upper 1-2 cm with still articulated, small (1-1.5 cm approx.) empty shells and, at greater depths, larger shells, also still articulated. Previous surveys of this area, in 1983 (Angus et al. 1985), and in July, 1986, (Amaratunga and Woo, unpublished data), had shown significant concentrations of live clams. The observed mortality must, therefore, have occurred in the period July, 1986, through April, 1987. The clam fishery is very important throughout the Annapolis Basin, providing up to 68% of the clam landings in the Scotia-Fundy Region of Nova Scotia in recent years (Angus et al. 1985). Therefore, this localized kill along with the apparent decline of stock throughout the Basin has received wide attention.

It is possible to get widespread mortality of organisms or population changes from an unfortunate conjunction of factors which are often difficult to determine (Harris 1984). In the Annapolis Basin, fishermen claim that the STRAFLO turbine at the causeway, which started generating tidal electrical power in 1984, has caused increased siltation of clam beds. This could adversely affect *M. arenaria* as was concluded, for example, in induced siltation experiments over tidal flats in nearby Minas Basin (Turk and Risk 1981). Although the causeway, which was originally built in 1960, would undoubtedly have had a greater impact on the Annapolis River and Basin, the tidal power station could also influence water currents and change phytoplankton production or its availability to clams for food.

Extreme variations of temperature and salinity or other environmental or physical factors could increase the stress on these molluscs. It is documented that major storms, hurricanes, or winter ice causing low salinity regimes or actual removal of invertebrates and sediment could periodically alter the distribution of intertidal or estaurine biota (Gordon and Desplanque 1983, Yeo and Risk 1979, Andrews 1973). One possibility in the Annapolis Basin was that a large slug of silt might have covered the flat during the winter months and led to smothering of the clams. This appears unlikely, however, since, throughout the affected area, neither barnacles nor mussels appeared to have suffered any unusual mortality.

The occurrence of extreme tides in the Fundy region might place unpredictable stress on intertidal animals (Bleakney 1972) as would the localized dumping of a toxic waste. Disease or predation is also a possible cause of clam death. Although not tested for other diseases, clams from Oak Point were sampled in 1986 for neoplasia (clam cancer) which proved negative (J. Cornick, Fish Health Unit, Halifax Fisheries Research Laboratory, pers. comm.). Many nemertean "ribbon" worms (*Cerebratulus lacteus*), known to be either a predator or scavenger of clams, were observed in the upper intertidal area of this site. Gastropods which are predators of bivalves, such as the snail, *Lunatia heros*, were also present.

In order to determine if the mortality might have been an isolated event, the Biological Sciences Branch set up two experimental plots in the Dead Clam Area (DCA) and a control plot was established at the high beach level where clams were apparently healthy. Assistance was requested from the Physical and Chemical Sciences Branch after the rapid and complete mortality of all experimental and control clams suggested the need to examine sediment from the area and clam tissue from those animals surviving in proximity to the control plot. Exposing healthy clams to sediment collected from the DCA could indicate the condition of the substrate ie. is the sediment the cause of the mortality and, if so, for what reason(s)? To verify if contaminants were present, analysis of sediment and clam tissue for toxic chemicals is also important. A preliminary study was carried out to see if Oak Point clams were possibly stressed in some manner which would make them more susceptable to *C. lacteus*. This report is the synthesis of a number of these investigations by the Habitat Ecology and Marine Chemistry Divisions to determine the cause and extent of the clam kill in the Annapolis Basin.

MATERIALS AND METHODS

Transplant Experiments

To determine if the mortality might have been an isolated event, experimental plots to monitor mortality rates were set up by the Habitat Ecology Division. Three 5 m x 7 m plots were established; two (A and B) were set up in the mid-tide area of the DCA and a control (C) in the upper beach area near the donor plot from which the clams for the experiment were taken (Fig. 2). Each plot was divided into 35 sub-plots of 1 m^2; 12 of these sub-plots were available for experimental plantings and the other 23 served as spacings for access between the experimental sub-plots (Fig. 3). In plot A, 12 sub-plots of 1 m^2 each were randomly assigned to be planted with either 50 or 100 marked (nail polish) clams in the centre 0.25 m^2 of the sub-plot. The marked clams, ranging 14-32 mm in shell length, were planted with even spacing between them and at a depth of roughly 30-60 mm. In plots B and

C, 50 marked clams were planted in each of 6 randomly assigned sub-plots. Plot C', a small 0.25 m² separate plot of 100 clams/0.25 m² very close to plot C, was set up using clams left over from those used to establish plot A. All plots were put in place between 27 May and 4 June 1987, with the intention of sampling them at one-month intervals (29 June, 29 July, and 28 August) for the first three months and subsequently at two mon intervals (26 November, 24 February, and 24 May).

On each sampling date, four randomly selected sub-plots were to be sampled; one of 50 and one of 100 clams/0.25 m² from plot A and one of those of 50 clams/0.25 m² from plots B and C. Following observation of mortality patterns up to 29 July, this sampling schedule was abandoned. Further and final sampling was undertaken on 5 August with one 100 clams/0.25 m² sub-plot of plot A and one 50 clams/0.25 m² sub-plot of plot B. Plot C' was also sampled on this date, as were two 0.1 m² areas of the donor plot.

For sampling, the centre 0.25 m² of each sub-plot was first marked using a grid and this central area of the plot, plus an additional 5-10 cm border on each side of this area, was dug out to a depth of approximately 15 cm. Samples were washed through a 1 mm² screen to ensure collection of both experimental animals and any small clams or recently set clam spat which might have occurred naturally in the samples. Any marked or unmarked clams as well as any marked valves were removed and counted.

Predation Experiments

During a visit to the area on August 12, we observed some areas of the upper beach 30-50 m upstream from the donor plot where soft-shell clams appeared to have been either predated or scavenged upon by *C. lacteus*. In these areas, both live and recently dead clams could be found; some of the dead with major portions of their body parts still intact. In some, a thick mucous blob was found in the empty mantle cavity. Nearby, there were areas of the beach with only live clams and no worms. In order to determine if the worms were predating on these bivalves or simply scavenging already dying or stressed clams, a rudimentary trial was set up in the Halifax Fisheries Research Laboratory. For this, four replicate groups of 14 Oak Point and 10 Cole Harbour clams along with 4 *C. lacteus* were placed in buckets filled with Oak Point sediment. The Cole Harbour clams, coming from an area near Dartmouth, Nova Scotia, where no mortality had been observed, were assumed to be unstressed. For identification, the Cole Harbour clams were marked with red nail polish. At the time the trial was set up, we had a separate worm-free container in which soft-shell clams from Cole Harbour had been held for an extensive period without significant mortality. Although the sediments in this container were not from Oak Point, we considered this an adequate control for the purposes intended. All buckets were held in filtered, running seawater in the Halifax Laboratory between 19 August and 5

October, 1987. One bucket was sampled on each of 24 August, 31 August, 23 September, and 5 October and live and dead clams as well as worms were counted.

Sediment Toxicological Experiments

It was also decided that the beach sediments should be examined for possible toxicity and on 5 October 1987, a further sampling and observational trip was made to the Annapolis Basin. Two sites were visited: mudflats at Thorne Cove, a productive area where clams are extensively fished, and the DCA at Oak Point (Fig. 1). At the DCA, approximately 55 L of sediment, collected to a depth of 20 cm, was taken at plot A (Fig. 2). Grab and core samples were also obtained at four plots (X, A, B, C) and any clams uncovered in the area were saved. Sediment was collected in a similar manner at Thorne Cove for use as control. Clams gathered at this location were purchased from a local fisherman. Thorne Cove was chosen as a control area since the control area used in the transplant experiments, having become affected by the mortality, was no longer useable. Thorne Cove is also well removed from the affected area.

In the lab, control and DCA-plot A sediment samples were sorted to remove any invertebrates which could cause predation or other problems. Control and DCA sediments were then divided and half of each autoclaved to eliminate microorganisms. Swabs for bacterial culture were taken immediately afterwards. Two replicate buckets of sediment, each containing 20 "healthy" clams from the control area, were placed into running seawater tanks in a quarantine laboratory to give the following conditions:

1) DCA sediment-raw (not autoclaved).
2) DCA sediment-autoclaved.
3) Control sediment-raw.
4) Control sediment-autoclaved.

The experiment began on 8 October 1987 and was completed on 7 January 1988. Tanks were monitored over the three month period to estimate the number of viable clams by observing siphon holes. On termination, sediment in each tank was sorted to remove all living clams to determine mortality. A body condition index was then calculated for each animal following the method outlined by Hawkins and Rowell (1987); the formula being:

condition index = 1000 X dry weight of meat/shell capacity

However, sediment was not purged from the guts of the clams so some error in the calculation of the condition index was introduced. The degree of consistancy of this error and its magnitude have been shown by Hawkins and Rowell (1987) to vary considerably. Clam length was measured along the long axis of the shell and the meat was visually examined. Shell length was plotted against total wet weight to verify normality in the data and sample distribution.

Surface oxidized and sub-surface reduced sediment grab samples were used for grain size and chemical analyses. In the laboratory, the samples were dried and subsampled. One portion of each sample was weighed and washed through a 63 micron sieve and the residue retained to determine the proportion of sand (63-2000 um) and mud (<63 um) in the samples. One portion was used for heavy metal analyses. The dried sample was weighed and decomposed in a mixture of HF and aqua regia. Total Zn, Cu, Pb, and Cd were determined using atomic absorption spectrophotometric methods (Rantala and Loring 1975; Rantala and Loring 1987).

Whole soft tissues from 3 DCA clams and 3 control clams were analysed for chlorinated pesticide residues and polychlorinated biphenyls according to the method of Addison and Zinck (1986).

RESULTS AND DISCUSSION

Transplant Experiments

Examination of the marked clam plots up to one week after planting revealed that the clams had established themselves and were actively pumping. First sampling of the sub-plots 25-34 days after planting, indicated a mortality range of 33-80% in experimental plots A and B and 79-82% in the control plot C (Table 1). The minimum in these ranges is based on the number of dead clams as a percentage of the total of live and dead clams recovered, while the maximum assumes that all live clams have been recovered and that "missing" dead clams can be accounted for by loss of the shell marking from some shells and/or physical displacement and death of the others. In plot A, we observed that many of the clams in one of the two sub-plots sampled had lost their markings, chips of nail polish being found on the screen or rubbing off a clam shell as it was handled. This did not occur to the same extent in any of the other plots, and, in the end, did not significantly influence the results. Since, other than those planted, there were no live clams in the two experimental plots the loss of shell marking influenced only the minimum of the range, causing a lower estimate of mortality. In the case of plot C, intended as a control, the finding of live but unmarked clams could have led to a lowering of the maximum in the range. This was not the case, however, in that no unmarked live clams were found. A second sampling of the plots, 55-64 days after planting, showed complete mortality in all four samples.

Further sampling, on 5 August, of the plots A and B and the small separate plot C' close to the control plot C also indicated the complete mortality of all clams. In one 0.10 m^2 sample taken from the donor plot, the articulated shells of 29 dead clams were recovered and no live clams were found. In the second sample, 16 dead and 17 live clams were found, indicating that some clams were still surviving in the upper reaches of the beach. Although

there was some evidence of snail predation in all of the plots examined, the incidence of drilled clams was generally quite low (2% or less). Predation by naticid snails found in the area, such as *Lunatia heros* and *Lunatia triseriata*, might however be underestimated when based only on freqency of drilled shells, since Schneider (1982) has reported the attack, without drilling, by another species of naticid, *Polinices duplicatus*, on the common razor clam, *Ensis directus*.

Predation Experiments

Results of the preliminary study to determine the relative susceptibility of Oak Point and Cole Harbour clams to predation by *C. lacteus* are presented in Table 2. The pattern of mortality for clams from both sources is very similar, suggesting that Oak Point clams, whether or not environmentally or otherwise stressed, were no more susceptable than clams from an area where no unusual mortalities had occured. Cole Harbour clams held without *C. lacteus* suffered no mortality during the same period. Although this control was not adequate to eliminate the possibility of sediment toxicity or sediment induced physiological stress, subsequent experiments did cover this aspect. That *C. lacteus* either predates or scavenges on *M. arenaria* and on other infaunal bivalves is well-documented from field observations (Wilson 1900; Coe 1943; McDermott 1976; Schneider 1982; Kalin 1984; McDermott and Roe 1985). Kalin (1984) describes *C. lacteus* as attacking *M. arenaria* by penetrating the siphon, probably with its thin proboscis, through either the excurrent or incurrent canal. McDermott (1976) describes a characteristic thick mucus being produced by *C. lacteus* in its area of attack on the razor clam (*E. directus*) and Kalin (1984) describes the head of *C. lacteus* lying in a clear fluid within the closed but otherwise empty valves of *M. arenaria*. Both in the upper beach level at Oak Point and in this predation study, we found recently dead clams with thick mucous blobs within the empty mantle cavity. It appears then that *C. lacteus* was predating heavily on clams in the upper beach areas, but we saw no evidence of this in the experimental plots (plots A and B), in the mid-tide area, or in the control plot C. Even if predation had been heavy throughout the area, it would be most unusual that a predator or group of predators would be able to affect a 100% mortality on the clam population.

On 5 October, when sediment was collected at site A of the DCA, no live clams were found although numerous empty shells were uncovered. No *C. lacteus* were observed. There was no unusual sedimentation and the area appeared healthy except for lack of *M. arenaria*. Only inshore of site C at the high water mark were a small number of clams found. A number of *C. lacteus* were also observed here. The many clam holes seen at Thorne Cove showed it was a relatively healthy area. At Thorne Cove, not many empty clam shells were uncovered while digging, nor were any *C. lacteus* observed. No *C. lacteus* were found in any of the material sorted in the laboratory although some polychaetes and small

unidentified worms were present in sediment from both collection sites. The abundance of *C. lacteus* in the DCA before the clam kill is unknown and, although predation by this worm as a cause of the mortality cannot be entirely ruled out, the fact that all sizes of clams were eliminated would argue against predation as the sole cause.

Sediment Toxicological Experiments

Results of the bioassays (Table 3) showed minimal loss of clams in all experiments. Whole dead animals were not found. Empty shells were found but the sediment from both collection sites previously had empty shells so it is not known if any were from the introduced clams. Because these shells were mixed in the sediment, a small number of living clams might have been missed in the sorting. However, the conclusion is that sediment from the DCA was not lethal to the clams during the experimental holding.

A body condition index on all animals was calculated to determine if clams in the DCA sediment had been under greater stress than those in the control sediment. This index, which reflects the physiological state of the animal, is based on the dry weight of the soft body tissue and shell length, and can vary due to a number of factors including geographical and temporal differences. Other factors affecting condition index are spawning, ration, height on shore, or environmental stress and pollution as described by Bayne et al. (1985). For example, Bayne and Thompson (1970) observed that fed mussels (*M. edulis*) had a higher condition index than unfed. They recognized the use of such "physiological indices that are both descriptive and predictive of stress to characterize natural as well as cultivated populations in order to monitor, e.g. the effects of pollution or artificial enrichment of the environment". In our experiments, all clams were nutritionally stressed because seawater to the tanks first passed through a sand-gravel filter removing most food material. The condition indices determined in our study were used to see if any additional environmental stress from the DCA sediment was indicated.

The mean condition indices (± standard deviation) for the four tanks (Table 3) indicates there was no difference between the abilities of raw or autoclaved sediment collected from either control or DCA areas to support the molluscs. In fact, the index of clams held in the control tanks was slightly but not significantly lower than the index of clams held in the DCA sediment. The condition index for the clams ranged 73.1-78.0 in the control sediment and 78.8-83.8 in the DCA sediment. An average index for all clams in the study was 78. Although the many variables make comparisons difficult, this average is lower than the 100+ condition index determined for *M. arenaria* collected in August 1983 in the Annapolis Basin (P. Woo, unpublished data). The higher value would be, in part, a reflection of more optimal summer conditions. In another study,

the index ranged 70-100 over the growing season (Feb.-Aug.) in Charlotte County (Bay of Fundy), New Brunswick (Robert and Smith 1980). Clams taken in Cole Harbour, Nova Scotia on 24 October 1985 had a mean of 75 (P. Woo, unpublished data). It would seem that the indices observed in our experiments are within those determined for clams from local areas in the natural state. Plots of weight versus length (Fig. 4) revealed no anomalies in the data.

Visual examination of the meat showed there were no abnormalities in the appearance of the tissue from any of the clams in the study. Clams held in the control sediment were nearer the surface than those in the DCA possibly because control sediment was coarser and packed harder making it more difficult for the clams to burrow. Temperature of the seawater in the tanks averaged 9.1°C in October, 8.9°C during November, and 5.2°C in December. At the termination of the experiment on 7 January 1988, water temperature had dropped to 3.0°C. These temperatures are similar to those found in water over tidal flats around the Bay of Fundy, October to January.

Swabs of sediment taken at the start of the experiment contained a small number of bacteria indicating that one portion of the autoclaved sediment was not completely sterile. Buckets containing this non-sterile sediment were then identified. At the end of the experiment, no clear difference in condition index, mortality, and appearance of the meat was observed between clams held in sterile and non-sterile autoclaved sediment from either collection site. This suggests that no toxic pathogenic or other debilitating microbes were present in the sediment collected in the DCA. The Fish Health Unit, Biological Sciences Branch, Halifax Fisheries Research Laboratory, confirmed that clams taken from the DCA on 5 October 1987 were free of disease and had normal histology (B. Zwicker and A. Moore, pers. comm.).

The results of the granulometric and heavy metal analyses are shown in Table 4. The sediments at both sites are muddy, fine-grained sands to sandy muds which, in core profiles, are characterized by a thin (0.1-1 cm) brownish oxidized layer on top beneath which is a brownish black to black reduced zone. The concentrations of Zn, Cu, Pb, and Cd in sediments collected in the DCA show little variation with depth or location on the mudflat and are comparable to those found in the sediment samples obtained from Thorne Cove. All metal concentrations are relatively low and are similar to those measured in texturally equivalent sediments at Peck's Cove, Cumberland Basin, Bay of Fundy. It appears that heavy metal concentrations at the DCA are at natural background levels for sediments of this type and there is no evidence to suggest heavy metal contamination.

Concentrations of chlorinated pesticide residues and polychlorinated biphenyls in clams collected from the DCA and control areas were identical and not significantly above reagent blanks. Minimal detectable limits were less than 5 ppb wet weight clam tissue. Although these clams collected inshore of

the area of the clam kill were not contaminated with pesticides or PCB's, it is not known what levels were present initially in animals within the DCA.

Conclusions

In conclusion, it is clear that a complete mortality of soft-shell clams occured over an area of the Oak Point clam flat at some time between July 1986 and April 1987 and that whatever mortality factors were acting continued to do so throughout the period of sampling up to and probably beyond August 1987. There was no evidence of excessive sediment buildup or other obvious environmental changes and, although there was some evidence of predation, it was not verified that this resulted in the complete mortality observed. Future studies are planned to investigate predation rates of *C. lacteus* on *M. arenaria*. These studies may provide further insights as to the extent and degree to which this worm may have been involved in the mortality. There appeared to be no detrimental effects, including mortality, on *M. arenaria* as a result of being held in sediment collected from the area of dead clams at Oak Point, Annapolis Basin. Sediment from Oak Point was not toxic and should now support clams; there is no evidence of heavy metal, pesticide, or PCB contamination. The reasons why soft-shell clams were not found there when sediments were collected is still unknown. As previously stated, a conjuction of negative factors, physical, chemical, and/or biological, possibly enhanced by such conditions as the large tide range of 9.3 m at this location, may have catalyzed clam mortalities. Spot sampling in 1987 indicated clams were present further upstream but the exact extent of the affected area, if it still exists, should be determined. A spatfall survey conducted in May 1988 indicated that, of the five flats sampled in the Annapolis Basin, only Oak Point had no surviving spat from the 1987 year class. The area should be further monitored for clam resettlement in 1988.

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Table 1. Mortalities observed in the Oak Point DCA during May-August, 1987.

Plot		Elapsed Days Since Planting	Planting Density No./0.25 m²	Marked Clams Recovered	Alive	Dead	Mortality* %
June 29	A	34	50	25	10	15	60-80
			100	95	64	31	33-36
	B	32	50	48	24	24	50-52
	C	25	50	43	9	34	79-82
July 29	A	64	50	17	0	17	100
			100	86	0	86	100
	B	62	50	47	0	47	100
	C	55	50	43	0	43	100
Aug 5	A	70	100	65	0	65	100
	B	68	50	35	0	35	100
	C'**	69	100	66	0	66	100

* minimum of range based on number of dead clams (generally shell only) as a percentage of total live and dead recovered, while maximum assumes that all live clams will have been caught and that "missing" dead clams are accounted for by loss of mark on shell and/or physical displacement and death

** C' was an individual 100/0.25 m² plot very close to plot C

Table 2. Percentages of Oak Point and Cole Harbour clams suffering mortality when held in Oak Point sediment along with the nemertean ribbon worm *Cerebratulus lacteus*.

Date	Mortality					
	Oak Point		Cole Harbour		Combined	
	Number	%	Number	%	Number	%
Aug. 19	0	0	0	0	0	0
Aug. 24	1	7	1	1	2	8
Aug. 31	3	21	5	50	8	33
Sept. 23	12	86	8	80	20	83
Oct. 5	14	100	10	100	24	100

Oak Point clams had a shell length range of 21-71 mm with a mean of 32 mm and s.d.=15 while the Cole Harbour clams ranged from 15-74 mm and s.d.=20.

Table 3. Annapolis Basin clam bioassay: mean condition index and shell length for soft-shell clams (*Mya arenaria*) held in control and DCA sediments (raw and autoclaved) from 8 October 1987 to 7 January 1988. Initially, two replicate buckets of sediment with 20 clams each were placed into the tanks.

Sediment Source and Treatment	Final Number of Live Clams	Mean Condition Index ±sd	Shell Length (mm)	Mean Shell Length ±sd	Comments
control	19	75.5± 8	37-57	45±4	
-raw	20	78.0±14	40-62	45±6	
	39*	76.8±11*	37-62*	45±5*	
control	20	75.1±27	40-54	47±4	sterile
-autoclaved	17	73.1± 6	40-57	48±4	not sterile
	37*	73.9±20*	40-57*	47±4*	
DCA	20	82.2±16	41-55	47±4	
-raw	18	78.8±12	38-58	47±5	
	38*	80.6±14*	38-58*	47±5*	
DCA	19	80.2±19	37-60	47±6	sterile
-autoclaved	20	83.8±30	39-58	48±6	not sterile
	39*	82.0±25*	37-60*	47±6*	

* composite of duplicate values

Table 4. Heavy metal concentrations (mg/kg dry wt.) and grain size in clam flat sediments from two sites in the Annapolis Basin, Oak Point (DCA) and Thorne Cove, collected on 5 October 1987. Concentrations in sediment from Peck's Cove, Cumberland Basin, Bay of Fundy are given for comparison.

Location	Sediment Layer	Grain Size % Sand	n	Heavy Metals Zn	Cu	Pb	Cd ug/kg*
Oak Point							
Plot X	Oxid.	59.8	1	44	13	18	96
	Anoxic	81.0	1	35	11	16	46
Plot A	Oxid.	14.5	1	58	13	20	64
	Anoxic	26.6	1	52	12	19	64
Plot B	Oxid.	18.5	1	48	10	18	55
	Anoxic	26.6	1	41	9	16	48
Plot C	Oxid.	89.0	1	37	11	12	52
	Anoxic	96.9	1	31	12	13	64
Thorne Cove							
	Oxid.	42.4	1	48	15	16	83
	Anoxic	35.7	1	47	15	18	72
Peck's Cove							
	0-1cm		2	65	12	18	47
	1-2cm		2	57	10	16	43

Oxid. = surface oxidized layer.
Anoxic = subsurface reduced layer.
* = note concentrations of Cd are reported in ug/kg (ppb)

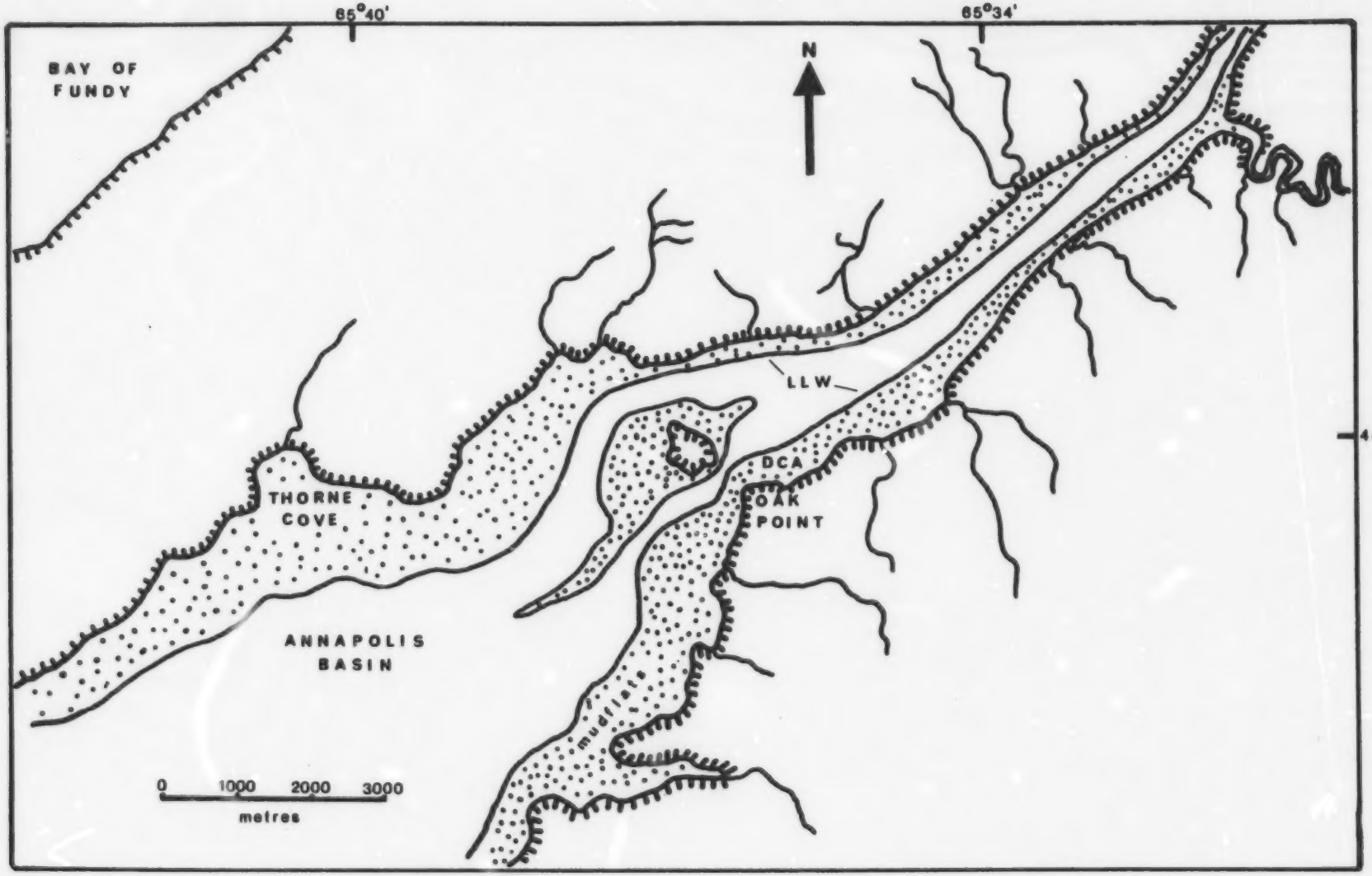

Fig. 1. Annapolis Basin, Nova Scotia, showing dead clam area (DCA) at Oak Point and the control area at Thorne Cove. LLW indicates lowest low water and the extent of the mudflats. Stippled area identifies approximate intertidal zone.

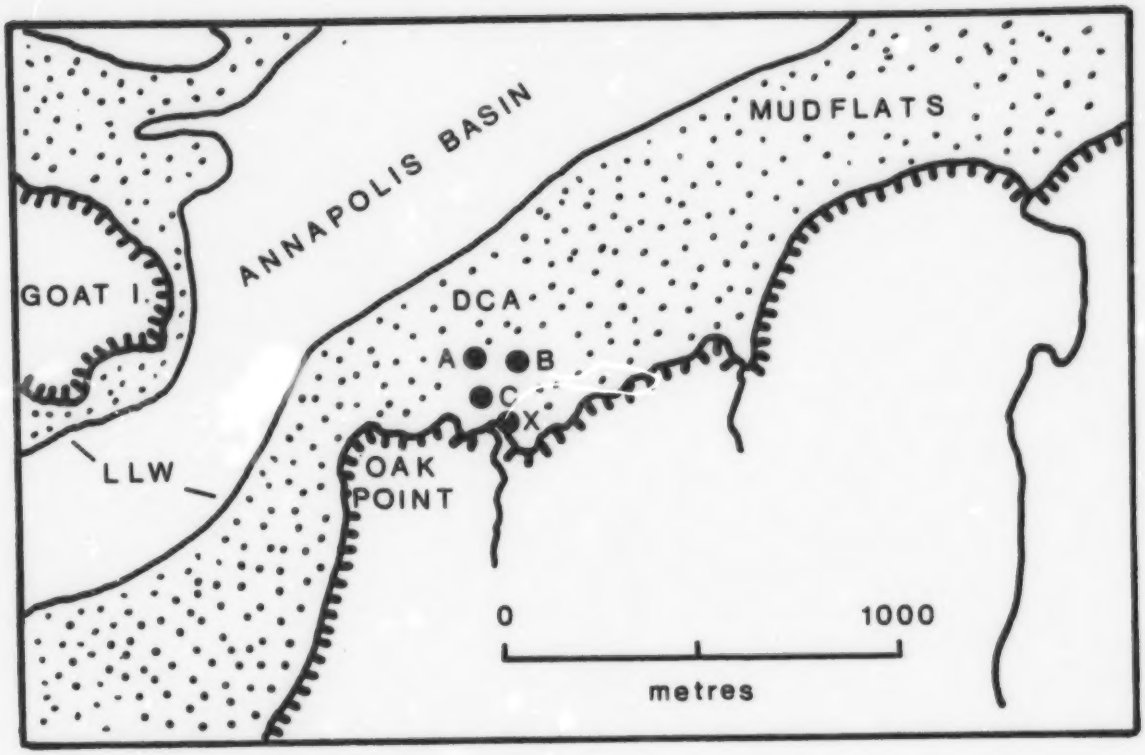

Fig. 2. Dead clam area (DCA) at Oak Point showing transplant and sample sites A,B,C, and X for the 1987 clam mortality study. LLW indicates lowest low water and stippled area identifies the intertidal mudflats.

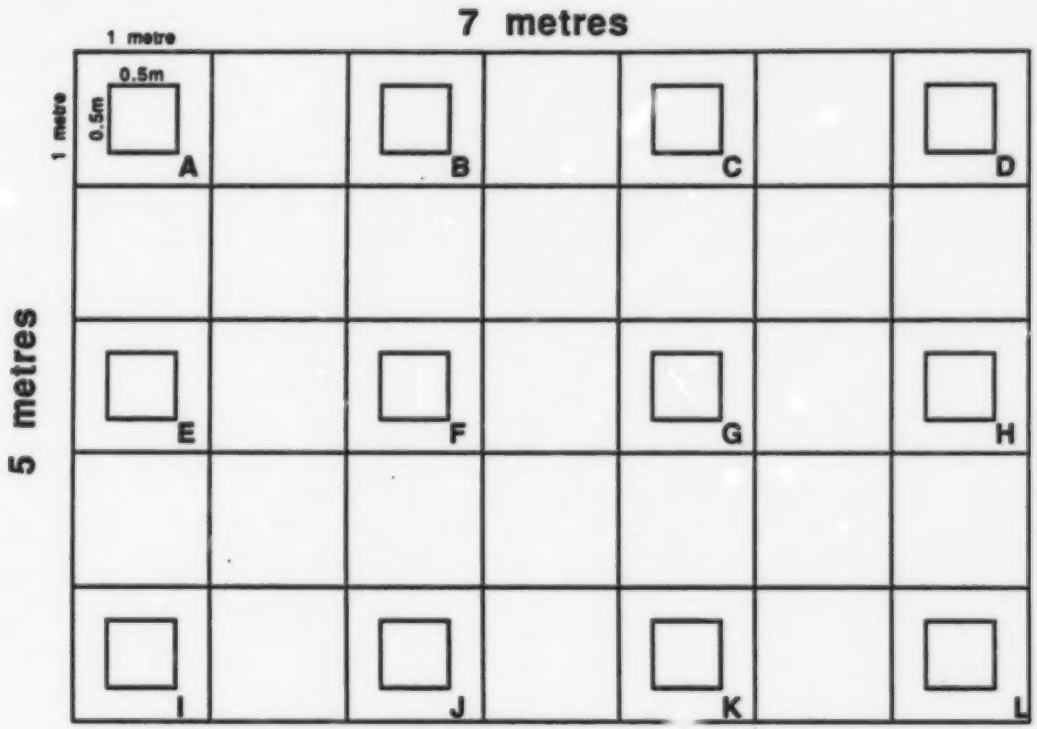

Fig. 3. Plot and sub-plot layout for the Oak Point mortality study.

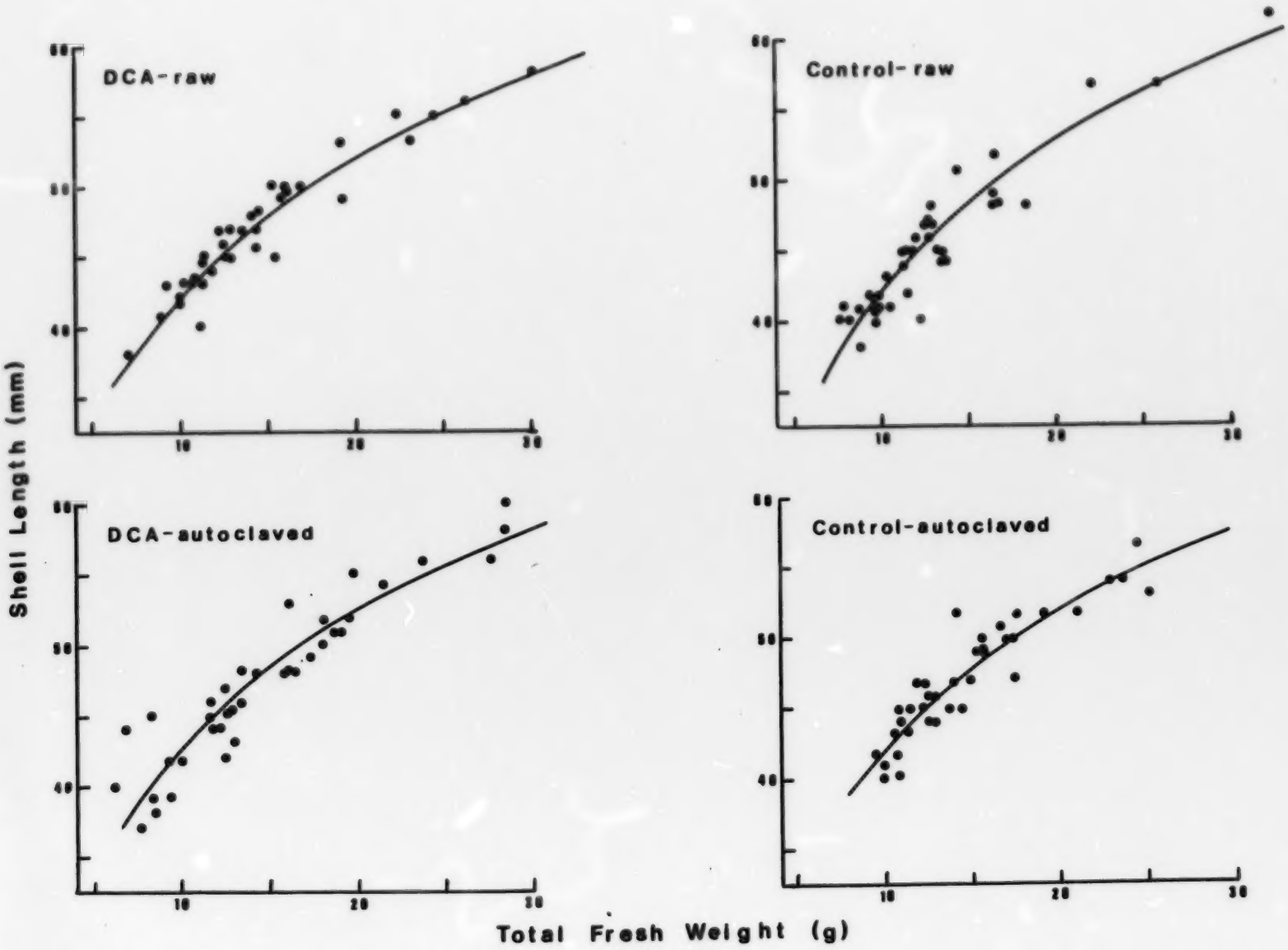

Fig. 4. Plots of shell length vs total wet weight for soft-shell clams in the bioassay using control and DCA sediments from Annapolis Basin completed 7 January 1988.